HIGH POWER TRENCH-BASED RECTIFIER WITH IMPROVED REVERSE BREAKDOWN CHARACTERISTIC

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of high power rectifiers.

2. Description of the Related Art

Semiconductor devices are increasingly required to accommodate high currents and/or high voltages without failing. For example, a variable speed pulse-width modulated (PWM) motor control circuit typically employs a number of transistors as switches, each of which has a flyback rectifier connected across it; the switches are closed in sequence to provide variable frequency AC power to a motor. The rectifier in this type of application is required to conduct a large current when forward-biased, and to block a high voltage when reverse-biased. To maximize the efficiency of the control circuit, the flyback rectifier ideally has a low forward voltage drop V_{FD}. The rectifier should also have a small stored charge Q_n, to increase switching speed, and a "soft" recovery with a small peak reverse current I_{RP}, to reduce the stress on the associated switching devices.

A number of power rectifier devices have been used to provide the high current and reverse blocking characteristics needed for such a high power application. One such device, the P-i-N rectifier, is shown in FIG. **1**. An N-type drift layer **10** is between an N^+ layer **12** and a P^+ layer **14** (X^+ denotes a carrier concentration of at least $1\times10^{18}/cm^3$, X^- denotes a carrier concentration of less than $5\times10^{16}/cm^3$). Metal on the P^+ and N^+ regions provide the rectifier's anode **16** and cathode **18**, respectively.

When forward-biased, P^+ region **14** injects large numbers of minority carriers into drift region **10**, greatly lowering the resistance of the drift region and allowing the rectifier to carry a high current density. The P-i-N rectifier's drift region **10** is usually thick, resulting in a high "blocking voltage"; i.e., the reverse voltage which the rectifier can accommodate without breaking down. These characteristics make the P-i-N rectifier useful for high power applications.

The P-i-N rectifier has several drawbacks, however. As described in J. Baliga, *Power Semiconductor Devices,* PWS Publishing Co. (1996) at p. 153, the P-i-N rectifier suffers from a "forward voltage overshoot" phenomenon, in which its V_{FD} at turn-on is higher than it is under steady-state conditions. This can be a serious problem in power circuit because the higher V_{FD} may appear across the emitter-base junction of a bipolar transitor used as an active element and exceed its breakdown voltage.

Another drawback of the P-i-N rectivier is its poor reverse recovery characteristic—as described in Baliga (ibid.) at p. 154. Reverse recovery occurs when the rectifier is switched from its on-state to its reverse blocking state. To undergo this transition, the minority carrier charge stored in the drift region during forward conduction must be removed, which requires the injected minority carriers to recombine with majority carriers. During recombination, some reverse current flows through the device before eventually decaying to zero. Because so many holes are injected into the drift region during forward conduction, recombination proceeds slowly in a P-i-N rectifier and thereby produces a poor reverse recovery characteristic.

Another rectifier device used in high power applications is the "merged P-i-N/Schottky" (MPS) rectifier, shown in FIG. **2** and described in Baliga (ibid.) at pp. 187–192. As

with the P-i-N rectifier, this device has an N-type drift region **20** on an N^+ region **22**. However, instead of a continuous P^+ layer over the drift region, two physically separate P^+ regions **24**, **26** are diffused into drift region **20**. Metal layers **28** and **30** provide the rectifier's anode and cathode, respectively. The interface between the anode **28** and the lightly doped drift region **20** form a Schottky contact **32**; the area under the Schottky contact is referred to herein as the Schottky region **34**.

When forward-biased, P^+ regions **24** and **26** inject holes into drift region **20**. This results in conductivity modulation of the drift region in a manner similar to the P-i-N rectifier, which reduces its resistance to current flow. The barrier height of the Schottky contact **32** is less than that of the structure's P^+-N junctions; if the Schottky region is sufficiently wide, a significant amount of current will flow through it, with the lower barrier height providing a lower V_{FD} for the device. The MPS rectifier also provides an improved reverse recovery characteristic: the injection level required to reduce the resistance in series with the Schottky region is not as large as that observed in the P-i-N rectifier; consequently, the stored charge in the MPS recitifer is smaller than that found in the P-i-N rectifier.

The MPS rectifier has several shortcomings, however. When reverse-biased, the device's Schottky contact **32** is subjected to a strong electric field. If unprotected, the Schottky contact exhibits a "barrier height lowering effect", which allows a reverse current to leak through the device via the lowered barrier. This can be a countered by reducing the spacing between the P^+ regions, but the device then begins to resemble the P-i-N structure—increasing the forward voltage drop and losing some of the advantages provided by the Schottky region. Unfortunately, this spacing is difficult to control, due to the lateral diffusion that occurs when fabricating the device.

SUMMARY OF THE INVENTION

A rectifier device is presented that overcomes the problems noted above. The rectifier is particularly well-suited to high power switching applications, providing a high current density and reverse blocking voltage, along with a low forward voltage drop and superior reverse recovery characteristics.

The novel structure has an N^- drift layer on an N^+ region. A pair of trenches are recessed into the drift layer opposite the N^+ region; the trenches are separated by a mesa region. Oxide side-walls line the outside of each trench. A shallow P^+ region extends from the bottom of each trench into the drift layer. The trenches each contain a conductive material that provides a conductive path between the top of the trench and its shallow P^+ region. The rectifier's anode is provided by a metal layer that contacts the conductive material in the two trenches and the mesa region; metal on the structure's N^+ region serves as the device's cathode.

The interface between the anode and the drift layer provides a Schottky contact. When forward-biased, the shallow P^+ regions inject holes into the drift region, lowering its resistance and allowing forward conduction through both the Schottky and P^+ regions. The Schottky contact's low barrier height gives the device a low forward voltage drop. When reversed-biased, depletion regions form around the shallow P^+ regions and the oxide side-walls and provide a potential barrier across the Schottky region which shields the Schottky contact, thereby providing a high reverse blocking voltage and greatly reducing reverse leakage current. The presence of the Schottky region also reduces the